AVIRIS REVEALS ANCIENT CHANGES IN SEA LEVEL WITHIN THE NEOPROTEROZOIC ROCKS OF SOUTHERN NEVADA

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1. INTRODUCTION

1.1 Nature and Scope of Project

During the 1996 flight season, AVIRIS data was acquired over the Spring Mountains of southern Nevada in association with the project "Tectonics of the southwestern U.S." (Ronald Blom, NASA-JPL, principal investigator). One part of this project involved collaboration between Ronald Blom and geology graduate student, Mark Abolins, at Caltech. As a first step in the tectonic investigation, AVIRIS data was used to examine the sedimentary rocks of the northwestern Spring Mountains. This study revealed evidence of an ancient change in sea level. This change left behind conglomerate that is easily seen on band ratio images. A preliminary investigation of conglomerate spectra suggests that this deposit is relatively poor in iron-bearing minerals and clay minerals. These mineralogical characteristics help AVIRIS discriminate between the conglomerate and other types of sedimentary rocks deposited during this interval of Earth history.

1.2 Previous Work

In the northwestern Spring Mountains, previous sedimentary studies (Burchfiel, 1964; Stewart, 1970) involved ground-based reconnaissance without the aid of remote sensing. As shown in Figure 1, sedimentary rocks in the northwestern Spring Mountains and adjacent areas were deposited during the late Neoproterozoic and early Paleozoic. As a result, these rocks contain a record of the climatic events that surrounded the radiation of animals with hard parts during the Cambrian. These climatic events included at least two glaciations during the Neoproterozoic. In addition, thesis work by MIT graduate student Catherine Summa (1993) and other recent investigations (Charlton and others, 1997) revealed possible evidence for another glaciation in the uppermost Johnnie Formation. To examine this evidence, the rocks in the uppermost Johnnie Formation were imaged with AVIRIS.

In other areas, several investigators have used remote sensing in the study of sedimentary rocks. Recently, Ernst and Paylor (1996) used multispectral data to produce improved maps of sedimentary rocks in the White-Inyo Mountains of California. In the early 1990's, Mary Kraus (1992) used multispectral data to study sedimentary facies in the Bighorn Basin of Wyoming. This study followed extensive earlier work in the Bighorn Basin by Lang and others (1987). This earlier work combined multispectral data with data from the Airborne Imaging Spectrometer (AIS), demonstrating the application of high spectral resolution data to the study of sedimentary rocks.

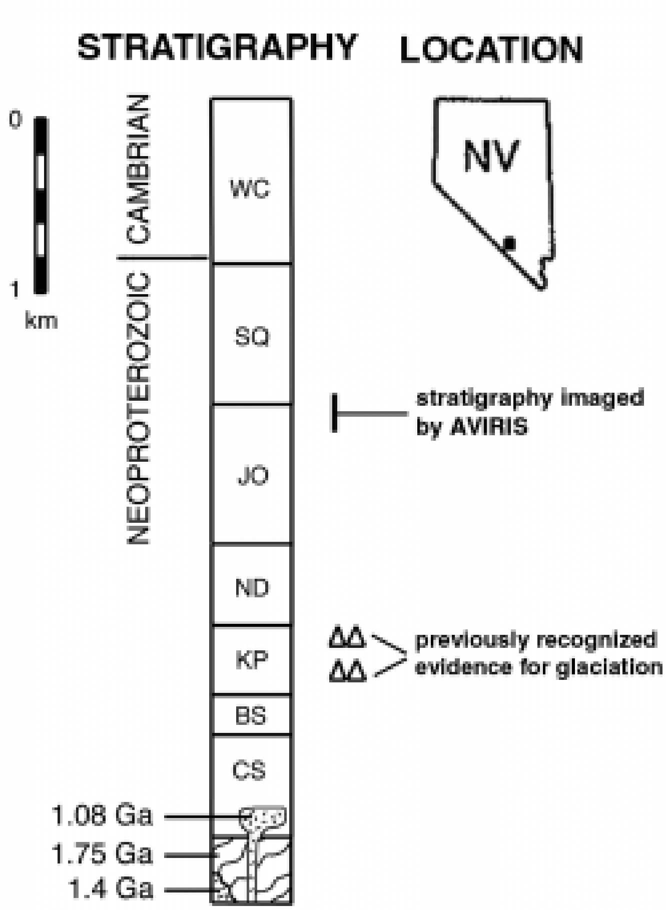

Figure 1. Stratigraphic column showing Neoproterozoic and Cambrian sedimentary rocks in the northwestern Spring Mountains and adjacent ranges. Sedimentary rocks post-date 1.08 Ga intrusions in the Crystal Spring Formation (CS). The sedimentary record includes evidence for two glaciations in the Kingston Peak Formation (Miller, 1982; Miller, 1985). Possible evidence for a third, younger glaciation in the uppermost Johnnie Formation (JO) was examined with AVIRIS. Formation names: CS, Crystal Spring Fm.; BS, Beck Spring Dolomite; KP, Kingston Peak Fm.; ND, Noonday Dolomite; JO, Johnnie Formation; SQ, Stirling Quartzite; WC, Wood Canyon Fm.

2. METHOD

As a first step in the study of sedimentary rocks in the northwestern Spring Mountains, a four-component image was produced from the AVIRIS data. Four-component Landsat TM images have been used by Robert Crippen, Ronald Blom, and others at NASA-JPL to discriminate different geologic units (e.g., Ford and others, 1990). Like a Landsat TM four-component image, an AVIRIS four-component image reveals different lithologic units.

Processing of the AVIRIS data involved four major steps. First, AVIRIS channels corresponding to Landsat TM bands were summed:

$BAND1$ = channel10 + channel11 + . . . + channel16
$BAND2$ = channel17 + channel18 + . . . + channel24
$BAND3$ = channel28 + channel29 + . . . + channel 35
$BAND4$ = channel44 + channel45 + . . . + channel57
$BAND5$ = channel127 + channel128 + . . . + channel146
$BAND7$ = channel182 + channel183 + . . . + channel207

Second, a band ratio image was produced from these bands:

$$\mathrm{RED}_{\mathrm{ratio}} = \frac{BAND5 - \min(BAND5)}{BAND7 - \min(BAND7)}$$

$$\mathrm{GREEN}_{\mathrm{ratio}} = \frac{BAND5 - \min(BAND5)}{BAND4 - \min(BAND4)}$$

$$\mathrm{BLUE}_{\mathrm{ratio}} = \frac{BAND3 - \min(BAND3)}{BAND1 - \min(BAND1)}$$

Third, a band average image was produced from bands 2, 3, and 4:

$$\mathrm{RED}_{\mathrm{avg}} = \mathrm{GREEN}_{\mathrm{avg}} = \mathrm{BLUE}_{\mathrm{avg}} = \frac{BAND2 + BAND3 + BAND4}{3}$$

Fourth, the band ratio and band average images were combined to produce the four-component image:

$\mathrm{RED} = .65\mathrm{RED}_{\mathrm{ratio}} + .35\mathrm{RED}_{\mathrm{avg}}$

$\mathrm{GREEN} = .65\mathrm{GREEN}_{\mathrm{ratio}} + .35\mathrm{GREEN}_{\mathrm{avg}}$

$\mathrm{BLUE} = .65\mathrm{BLUE}_{\mathrm{ratio}} + .35\mathrm{BLUE}_{\mathrm{avg}}$

3. RESULTS

Four-component AVIRIS images reveal a number of lithologic units in the northwestern Spring Mountains, NV. In most areas, siltstone and grayish-purple fine sandstone occur at the top of the Johnnie Formation. These lithologic units are labeled "sts" and "ss," respectively, on Figure 2. In the area shown on this figure, the sedimentary rocks dip to the east-southeast, so the oldest rocks are on the left-hand-side of the figure and the youngest rocks are on the right-hand-side. Consequently, the fine sandstone was deposited first, the siltstone was deposited on top of it, and the Stirling Quartzite (labeled "q") was deposited on top of the siltstone.

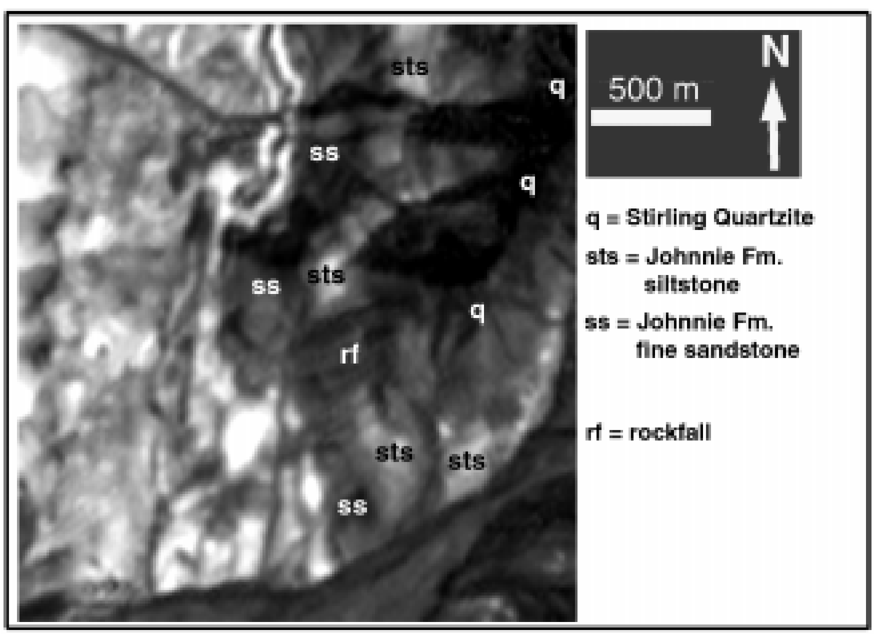

Figure 2. Grayscale copy of a color four-component AVIRIS image from the northwestern Spring Mountains, NV. Grayish-purple fine sandstone (ss) and the Stirling Quartzite (q) appear dark, while siltstone (sts) appears bright. Locally, the siltstone is covered by quartzite talus shed by the elevated area on the right side of the image. The letters "rf" denote a particularly large rockfall.

At one location in the northwestern Spring Mountains, AVIRIS images reveal an additional sedimentary deposit at the top of the Johnnie Formation. As shown in Figure 3, conglomerate (cg) is present along with fine sandstone and siltstone. In the area shown on Figure 3, the sedimentary rocks dip to the north, so the oldest rocks are on the south side of the figure and the youngest rocks are on the north side. Consequently, the fine sandstone was deposited first, the conglomerate was deposited on top of the fine sandstone, the siltstone was deposited on the conglomerate, and the Stirling Quartzite was deposited on the siltstone.

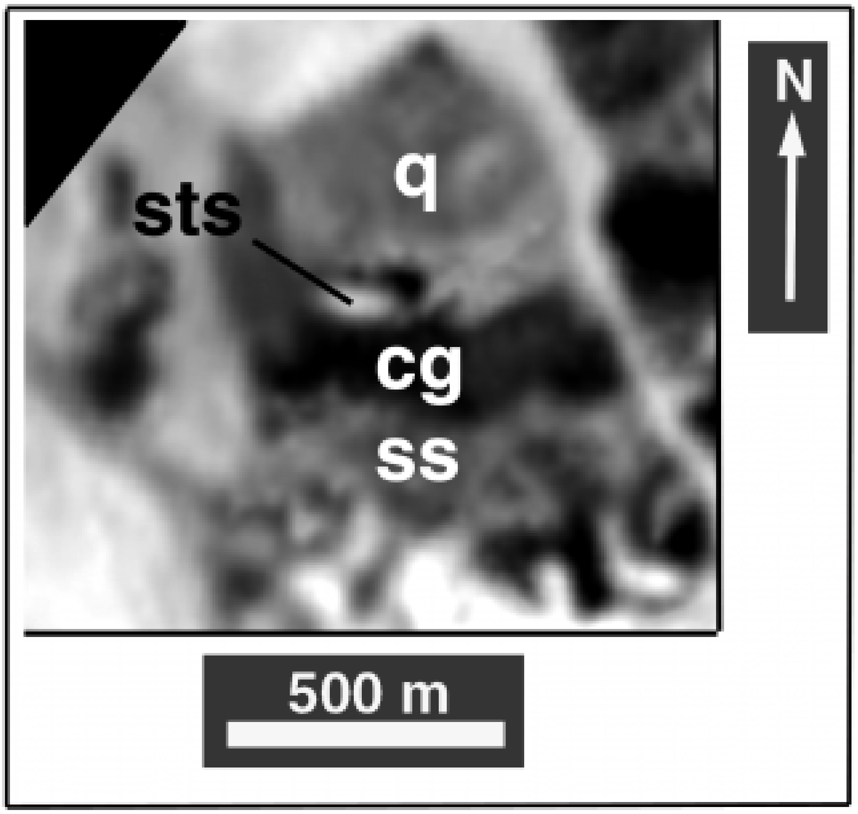

Figure 3. Grayscale copy of a color four-component AVIRIS image from the northwestern Spring Mountains, NV. A conglomerate deposit (cg) is present at this location, but not in the area shown on Figure 2. The Stirling Quartzite (q), siltstone (sts), and fine sandstone (ss) are present at both locations.

4. DISCUSSION

4.1 Interpretation of Results from the Spring Mountains

The conglomerate shown on Figure 3 is best interpreted as a deposit that formed after a large drop in sea level (Charlton and other, 1997). In this interpretation, a series of five steps resulted in the stratigraphy observed at the top of the Johnnie Formation. These five steps are illustrated in Figure 4. First, fine sandstone was deposited in a shallow sea. Second, siltstone was deposited on top of the fine sandstone. Third, sea level fell, and the area was exposed to sub-aerial erosion. A valley was eroded in the area shown in Figure 2, removing the siltstone and some of the fine sandstone. Fourth, conglomerate and siltstone were deposited within the canyon. Fifth, sea level rose again and the Stirling Quartzite was deposited throughout the area.

Similar valley fill deposits have been mapped with the aid of aerial photography in the Pyrenees (Sgavetti, 1991). In the Pyrenees, similar geologic relations were created by the erosion and filling of submarine canyons within marine deposits during the Eocene.

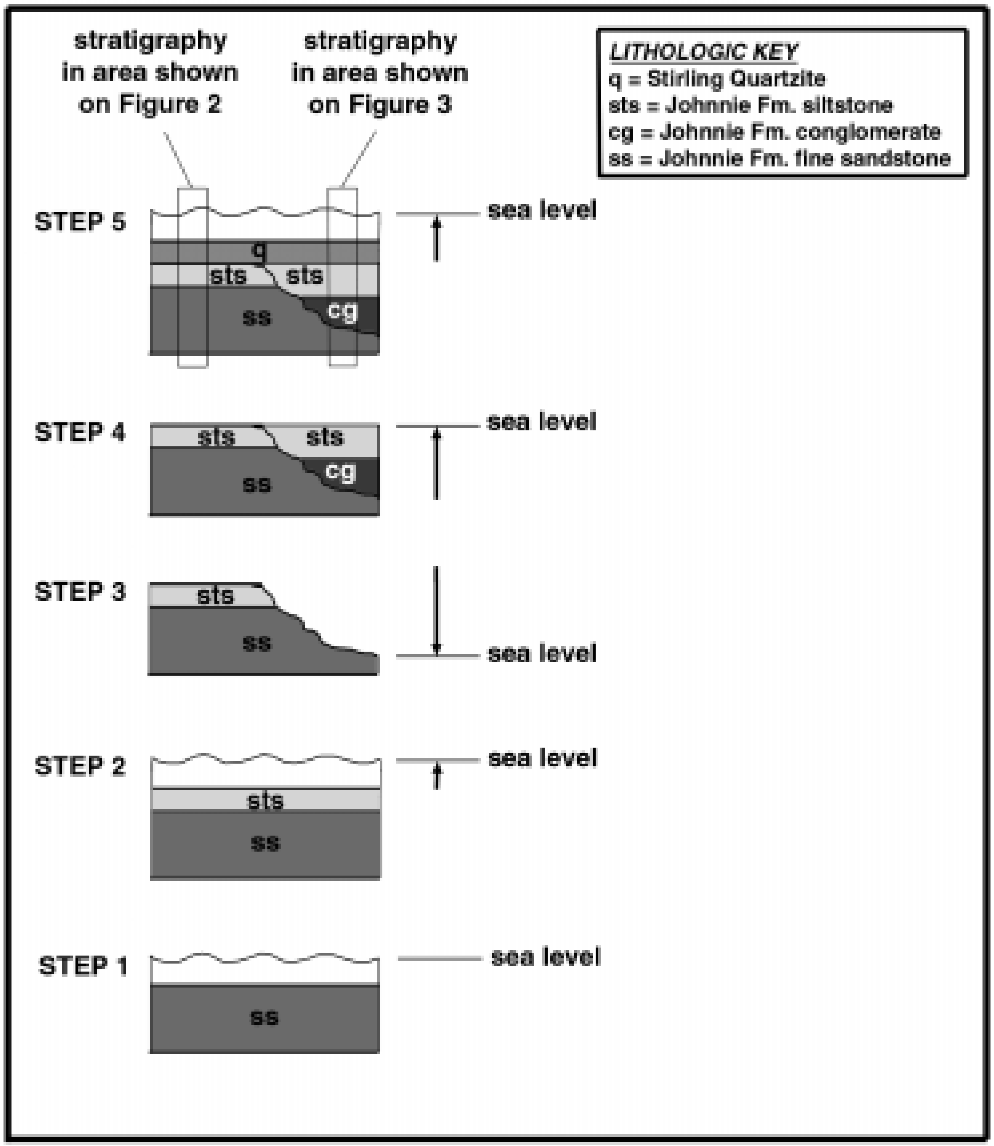

Figure 4. Effects of sea level change on sedimentary deposits now exposed in the northwestern Spring Mountains, NV. The arrow indicates the change in relative sea level between each step and the preceding step. See the text for an explanation of each step.

4.2 A First Look at Spectral Differences

Preliminary investigation of AVIRIS spectra from the conglomerate and fine sandstone suggests a relative lack of iron-bearing minerals and clay minerals in the conglomerate. Spectral radiance data was used to compare the two lithologic units. No atmospheric correction has been applied and radiance data has not been converted to reflectance.

To compare the two units, spectra were extracted from 46 pixels within the fine sandstone and 83 pixels within the conglomerate (Figure 5). For each unit, relatively pure pixels were identified by fitting a two-component linear mixing model to the data. A linear mixing model of this type is shown in Figure 6. In this model, pure spectra are a linear mixture of a bright "pure rock" component and a dark "shadow" component. Spectra that are not linear mixtures of pure rock and shadow were excluded from the comparison.

Spectra from pure pixels were ratioed and the result is shown in Figure 7. As shown in Figure 7, the fine sandstone is generally brighter than the conglomerate. However, the conglomerate lacks two absorption features that are present in the fine sandstone. One absorption feature is present at wavelengths of less than 1120 nm and probably involves Fe-bearing minerals. The other feature is centered at 2210 nm and probably involves OH in clay minerals. The relative lack of iron-bearing minerals and clay minerals in the conglomerate distinguish it from the underlying fine sandstone.

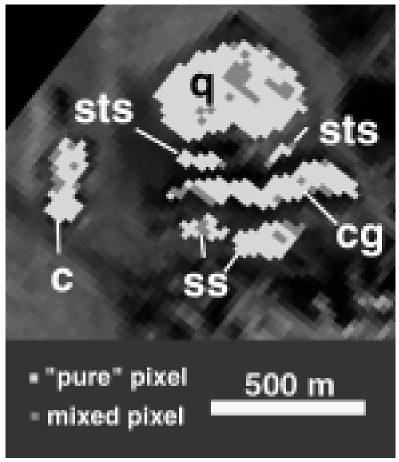

Figure 5. Pixels selected for comparison between different lithologic units. Area shown is the same as in Figure 3. "Pure" pixels can be modeled as a linear mixture of a bright "pure rock" and dark "shadow" components (see Figure 6). Pure pixels were used in the comparison between the conglomerate and fine sandstone shown in Figure 7. Lithologies: ss = fine sandstone, cg = conglomerate.

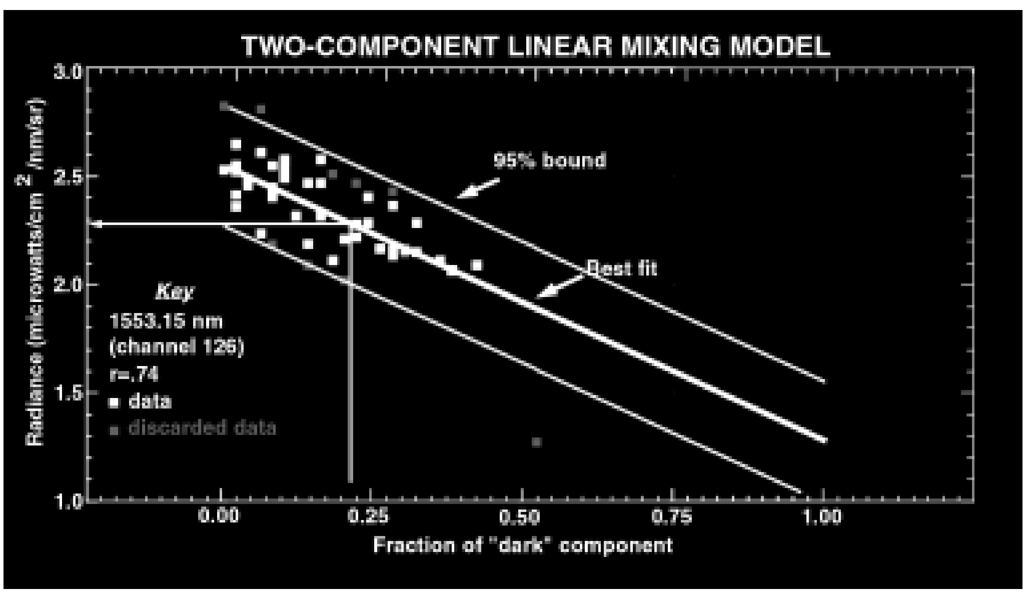

Figure 6. Two-component linear mixing model for fine sandstone. Each square represents the radiance of one pixel from Figure 5. A straight line was fitted to the data and empirical 95% bounds were calculated. Data sitting outside the 95% bound in more than 25 channels was discarded (dark squares). As a result, some data that sits close to the best-fit line for channel 126 has been discarded because of information from other channels. Discarded data is shown as mixed pixels on Figure 5. The midpoint radiance of the pure pixels (arrow) was selected for the comparison shown in Figure 7.

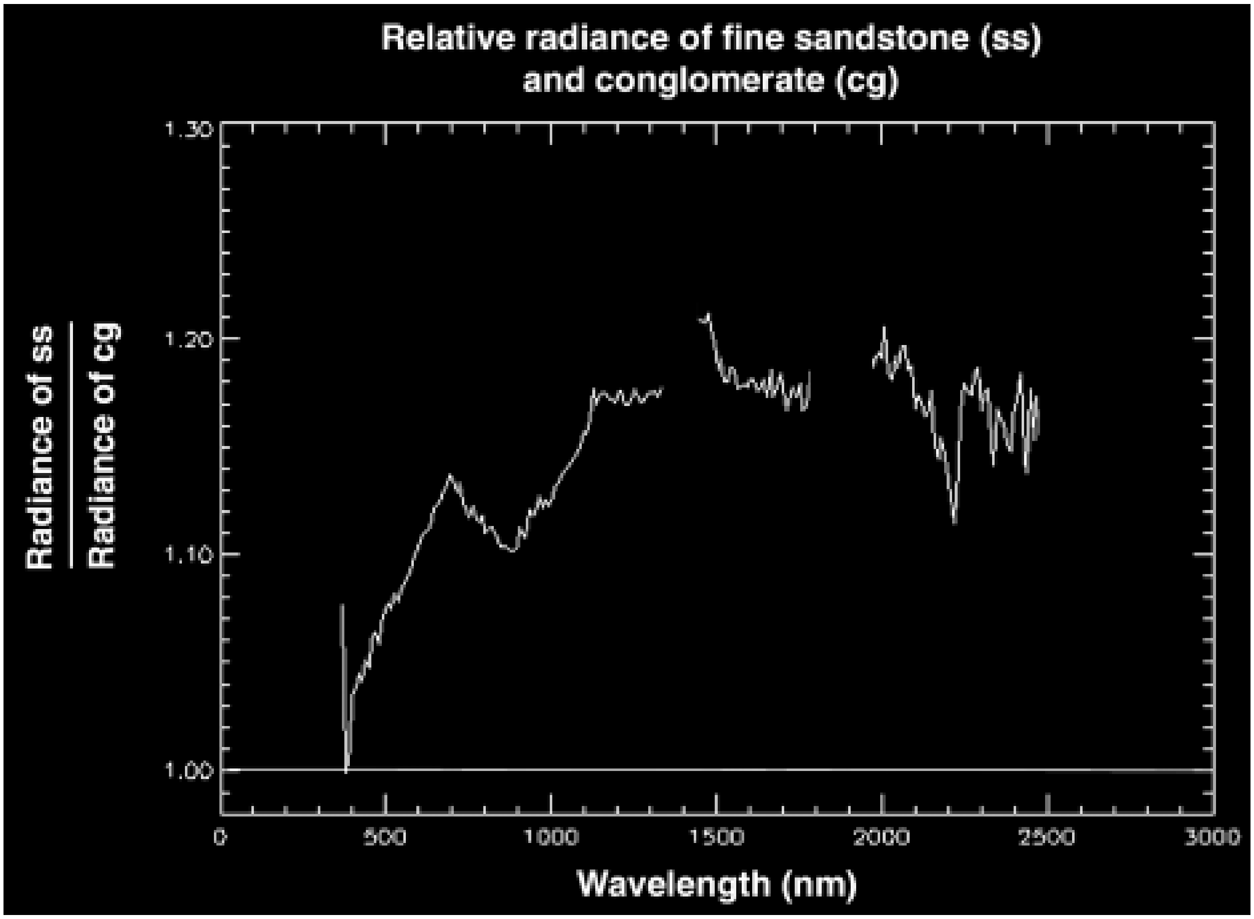

Figure 7. Comparison of fine sandstone and conglomerate. See Figure 5 for the location of pixels used in the comparison, and Figure 6 for an explanation of the radiance values used in the ratio.

5. CONCLUSION

AVIRIS images from the northwestern Spring Mountains, NV reveal conglomerate that was probably deposited within a valley after a drop in sea level. Four-component images show that the conglomerate is present locally near the top of the Neoproterozoic Johnnie Formation. Preliminary spectral investigations suggest that a relative lack of iron-bearing minerals and clay minerals in the conglomerate helps to distinguish it from the underlying fine sandstone. These findings emphasize the utility of AVIRIS in elucidating important events in the stratigraphic record.

6. ACKNOWLEDGEMENTS

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